Metrology and Control of Large Telescopes

UPGRADED GMRT SERVO SYSTEM

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Giant Meter wave Radio Telescope - GMRT

The GMRT is a large aperture synthesis radio telescope operating at frequency range 50Mhz – 1450Mhz .

Designed, built and operated by National Centre for Radio Astrophysics is located 80 km north of Pune in India.

This telescope consists of:

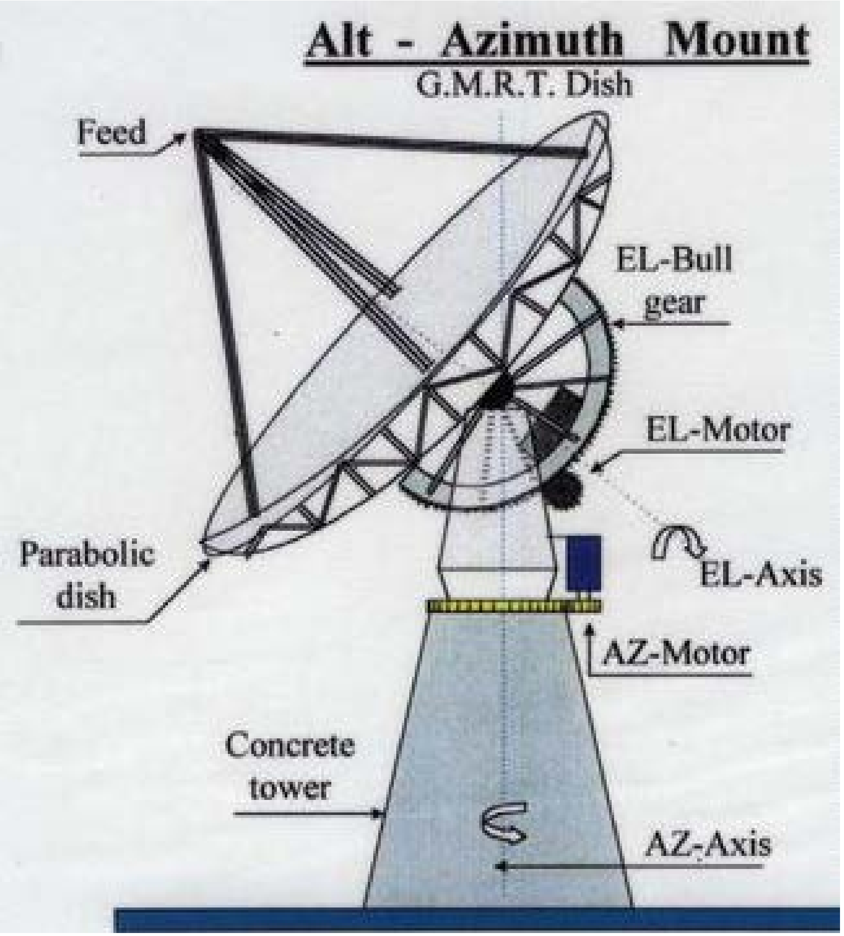
- 30 identical antenna dishes of
- 45m reflector diameter.

- 14 antennas are spread over area of about one km square.

- 16 are distributed along Y-formed arms giving an interferometric baseline of 25 kilometers.

GMRT Servo System

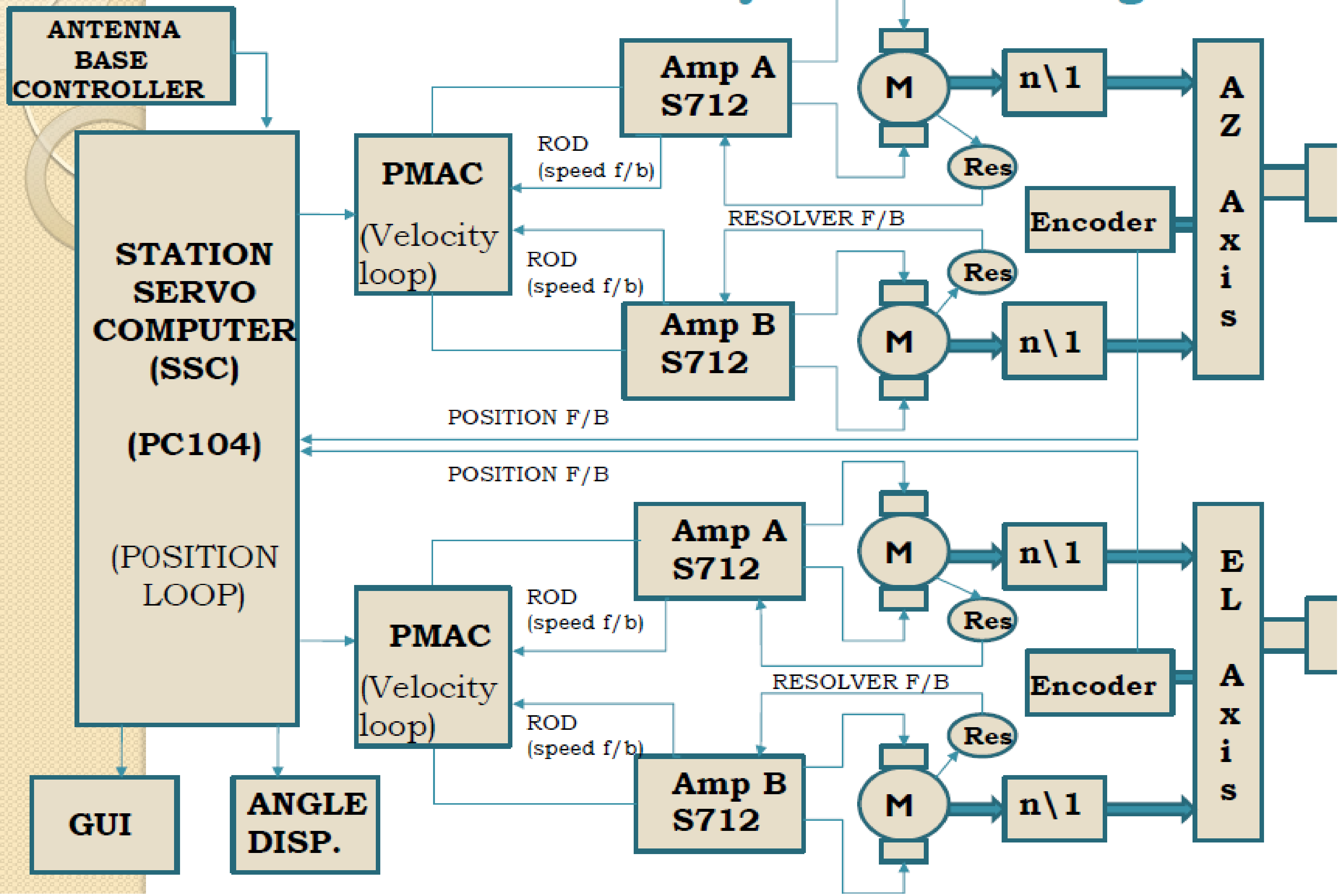
- Requirement of Servo System in Large Radio Telescopes,
  - Ability to point anywhere in the sky,
  - High Pointing and Tracking accuracy,
  - Able to accelerate rapidly in the direction of source,
  - Able to manoeuver remotely,
- Dual Drive Closed Loop Position Feedback Control System.
- Location: Base of the each Antenna



GMRT Servo System Specifications

Parameters	Values
Dish Mount	Altitude-Azimuth mount
Drive	Dual drive in Counter Torque mode
Dish Movement	AZ: ±270deg EL: 15deg to 110deg
Dish Slewing Speed	AZ: 30deg/min EL: 20deg/min
Min Tracking Speed	AZ: 5arcmin/min EL: 5 arcmin/min
Max. Tracking Speed	AZ: 150arcmin/min EL: 15 arcmin/min
Tracking acceleration	< 0.02 deg / sec / sec (Az and EL)
Position measurement accuracy	20 arc seconds
Tracking & Pointing accuracy	1 arc min for wind speed < 20kmph
Design Wind Speed	40 KMPH Operational 133 KMPH Survival

GMRT Servo Control System Block Diagram



Older drive configuration

- The existing motor drive system used on the azimuth and elevation axes of GMRT antenna dishes employs:
- DC-brush motors, designed and manufactured over 20 years ago.
- Reduction via 3-stage planetary gear boxes, driving toothed drive rings.
  Reduction c. 25,000:1.
- Load inertia c.10^6kg.m²
- Stiffness c. 10^7Nm/Rad
- Tracking accuracy = 1 arc min.
- Backlash compensation by analog
- The position controller is 86X based running in 'Pascal'

Need for upgrade

Motors

The existing drive and control system has worked well for many years, however exhibits

- high maintenance costs(brush wear etc)
- limited accuracy.
- Obsolete.

It was decided to retrofit :

- To increase life of basic telescope system
- Reduce maintenance cost and down time

Motor maintenance being labour intensive required schedule down time. Almost 30 days in a year of telescope time is lost.

Need for upgrade

Savings in telescope Cost

- Cost of motors of 30 antennas (in 1991) - Rs480 lakhs
  ~ $0.95 million
- Cost of servicing @Rs25Lakhs per year
  is Rs.500 lakhs in 20 yrs.
  ~ $1 million
- Equivalent to a cost of
  brush less drives
  of 10 # antennas of GMRT**.**

PM DC Brush Motor

Savings in telescope time

Time gained = 8hrs x 30 days
= 240 hrs per annum.

Need for upgrade

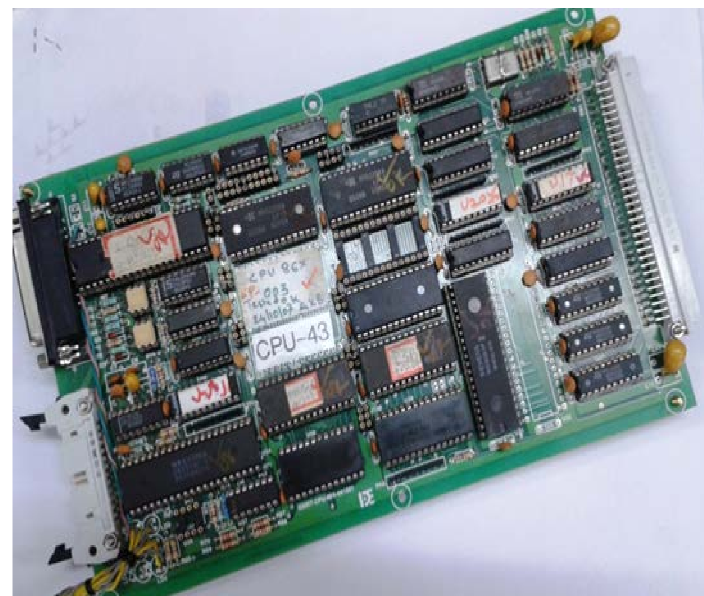
Position Controller

The position controller implemented in 86X based computer designed in 1991 was state-of-art as it implemented *state machine* to carry out the real time task and worked satisfactorily.

The main motivation to retrofit 86X with PC-104 single board computer(SBC) was due to :

- Limitations in hardware
- Outdated development tools of software
- Custom made scheduler
- Obsolescence
- Implementing modern control algorithm Was not possible.

86X CPU board



Retrofit and upgrade

- **The PC-104 based SBC** is available commercially off the shelf.
- Tools for firmware and software developments are ready made.
- The control algorithm Software is developed on the Linux OS therefore changes can be easily implemented in software.
- PC-104 is based on PCI bus standard so the *connector (signals*) and *form factor* do not change with processor.
  Even if the processor changes the software will run on the new processor without the need for major change in software.

PC-104 SBC

- The smaller version of Linux namely "Puppy Linux" is the OS .
- As the scheduling in Linux does not guarantee a real time servicing of requests, a special Linux - RTAI is used to control real time tasks.

Retrofit and upgrade

The 4 brush motors in azimuth/elevation are replaced by **4 brushless motors** with up to 20 N-m continuous torque, 1,500rpm max. speed, with resolver feedback and holding brakes.

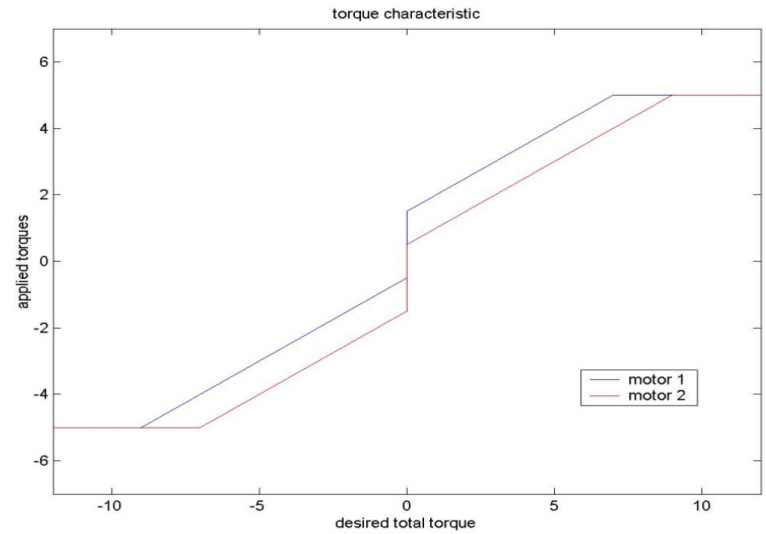
Modern, **digital motor drive amplifiers** are employed, which have high resolution and bandwidth.

The upgraded control system with high Resolution sensors will provide a ten fold Improvement in tracking accuracy

- 10 arcseconds.

Backlash compensation

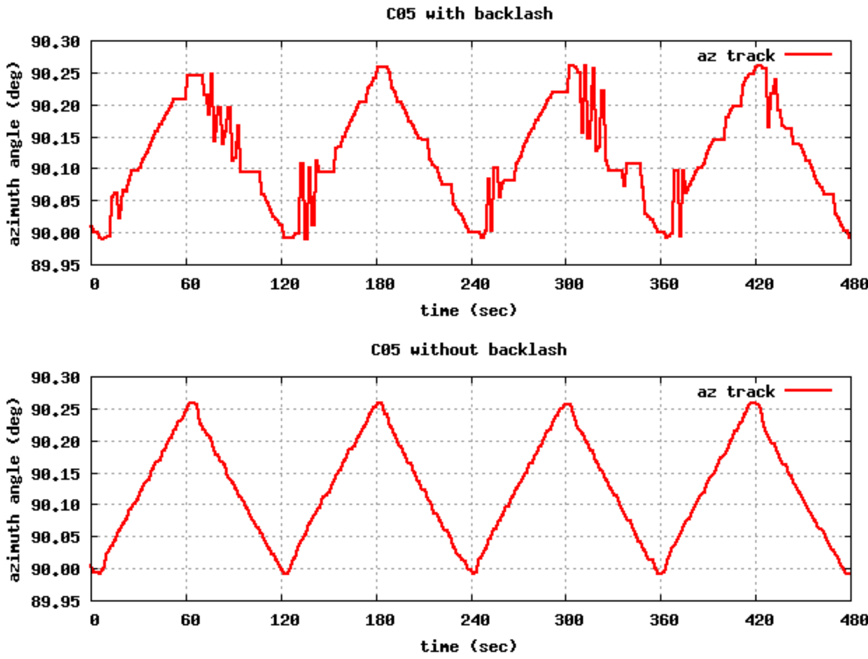
Backlash compensation is achieved by using 2 motors with torque offset, adjustable in software.
The characteristic is shown



It exhibits hysterisis on sign change of position error polarity.

Typical offset is 10% of peak torque.

The gear train hysterisis or backlash Is measured to be around +/- 3.5 arc minute with reference to o/p encoder.



The second figure shows the effect when positioning with reversing Torque. This is as per expectation In the book by Gawronski.

Upgraded Control system Configuration

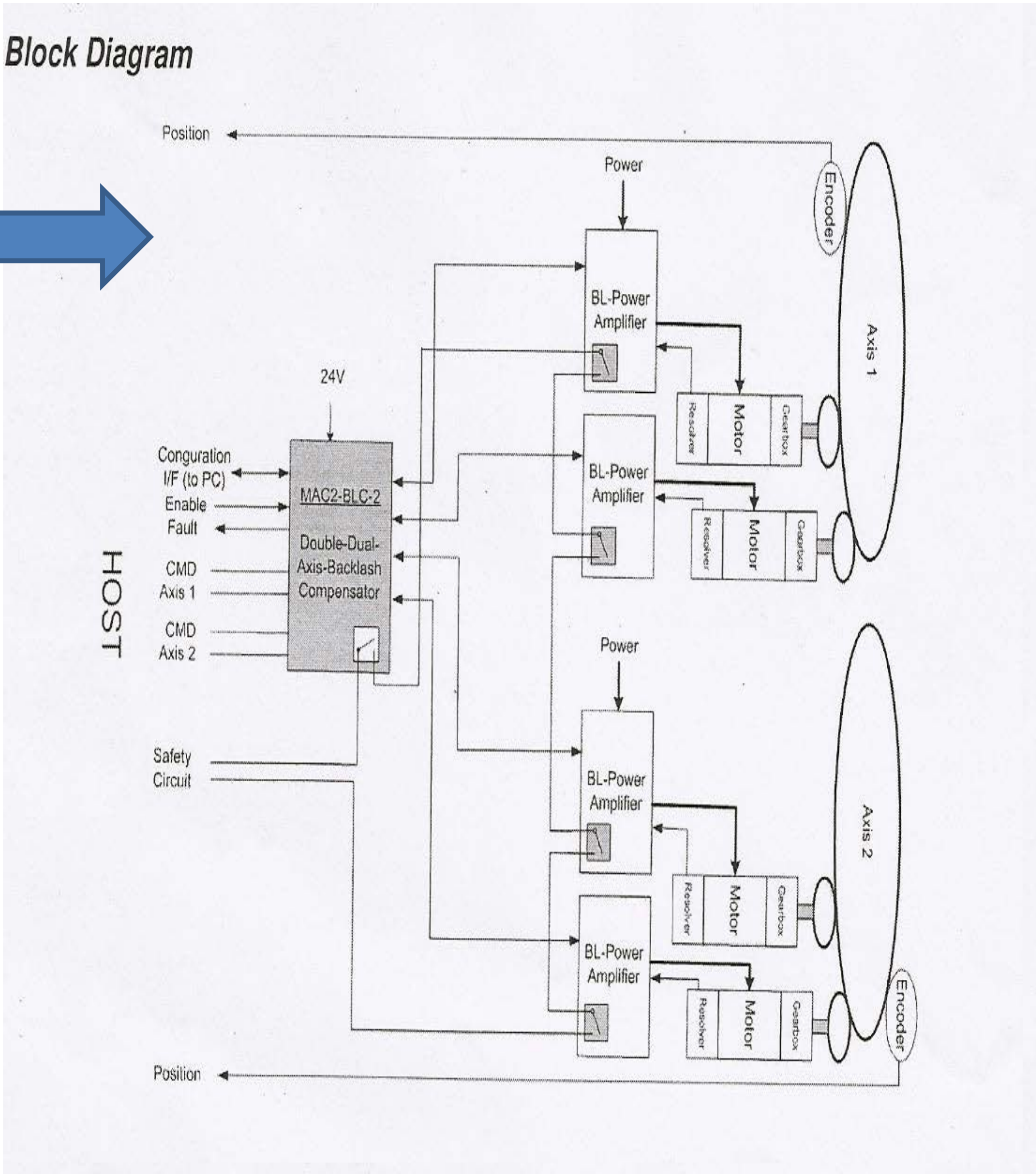
Each Az / Elevation axis has:

- 1 backlash compensation unit
- 2 drives, 2 motors & resolvers

.

The backlash units accepts a speed command and applies a differential torque offset before commanding a physical torque from each of the two drives in each axis.

This configuration solely provides precise torque control in each axis.

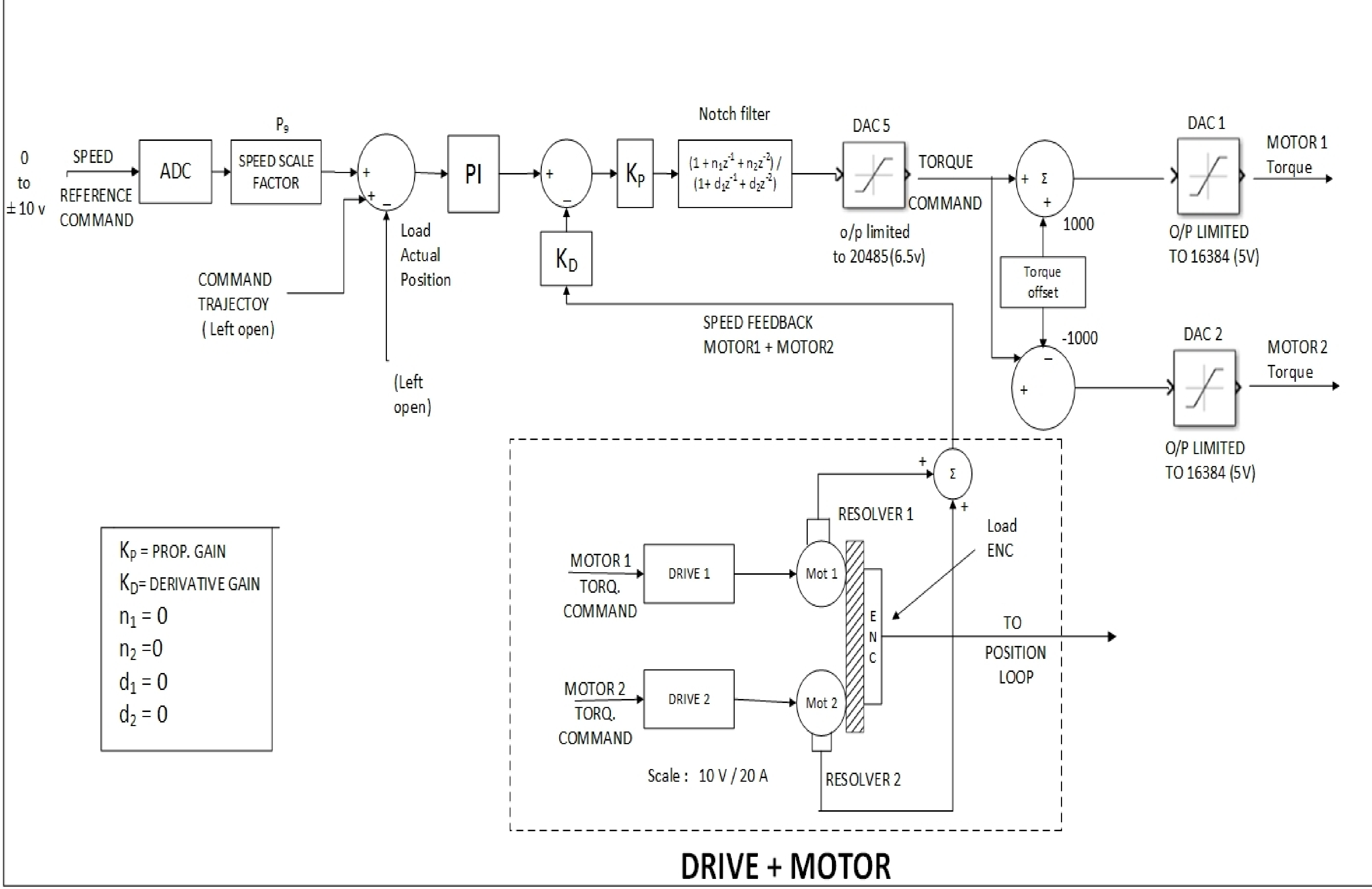


Upgraded Control system configuration

- The backlash control unit has full velocity control capabilities and so supports complex algorithms like PID with notch filter, feed forward and others. The next slide shows the backlash control unit customized for GMRT.

- The monitoring tools in the backlash unit is used for performing tests like speed characterization, step response and locked rotor frequency.

BLOCK DIAGRAM OF (DT-PMAC) CONFIGURED AS SPEED LOOP WITH BACK LASH COMPENSATOR



DRIVE + MOTOR

EMC of the electronic cabinet

- The EMC cabinet housing the drives is developed specially to mitigate the self generated RFI due to the switching of transistors and devices with in.
- The cabinet is tested at Mooser GmbH, labs in Germany.
- The screening attenuation obtained is 20 dB in the frequency range 200Mhz - 1500Mhz.
- Another test was performed at the telescope site after the brush less sys. is commissioned to verify RFI.
- Two measurements are made:
  - i) BL drive power put out
  - Ii) BL drive energized
- A log periodic antenna with an amplifier and Spectrum analyser was used to detect RFI in both polarizations.

Maccon GmbH	Page 6 of 16	2010-06-25
Dr. Schneider, Maccon GmbH		
Mr. Marahrens, Maccon GmbH		
Mr. Heina, Mooser Consulting GmbH		
Doc.-No. 210/2010, Screening attenuation of an empty electronic cabinet		
Note: This document does not replace a test report!		

MOOSER

Measurement plots:

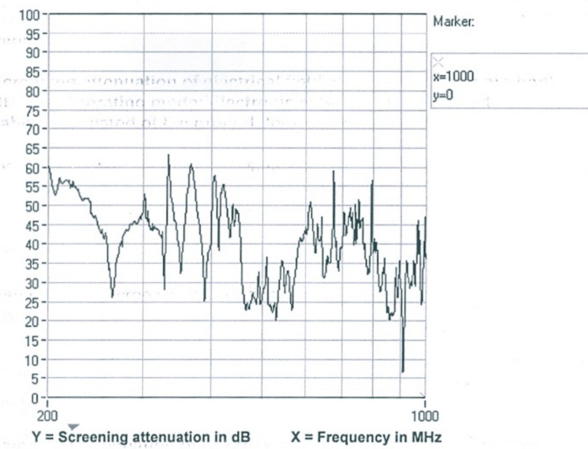
Test 1.1.1 **Screening attenuation of electrical field-strength (antenna method)**
DUT #1, Operating mode: Electronic cabinet, empty, closed, cabinet insulated of the ground floor

Settings:
- f: 200-1000 MHz
- Δf: 1 MHz
- Det: AV
- BW: 9 kHz
- T: 20 ms

Antenna: horizontal

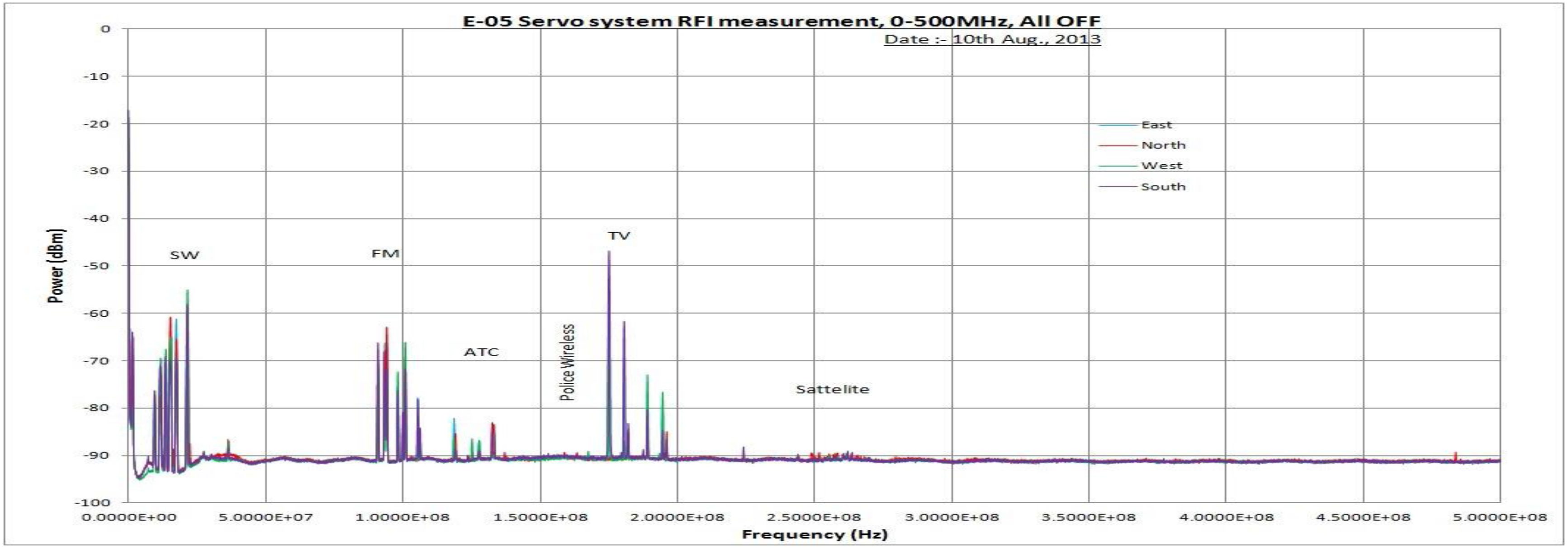
File: TEST_41.DAT

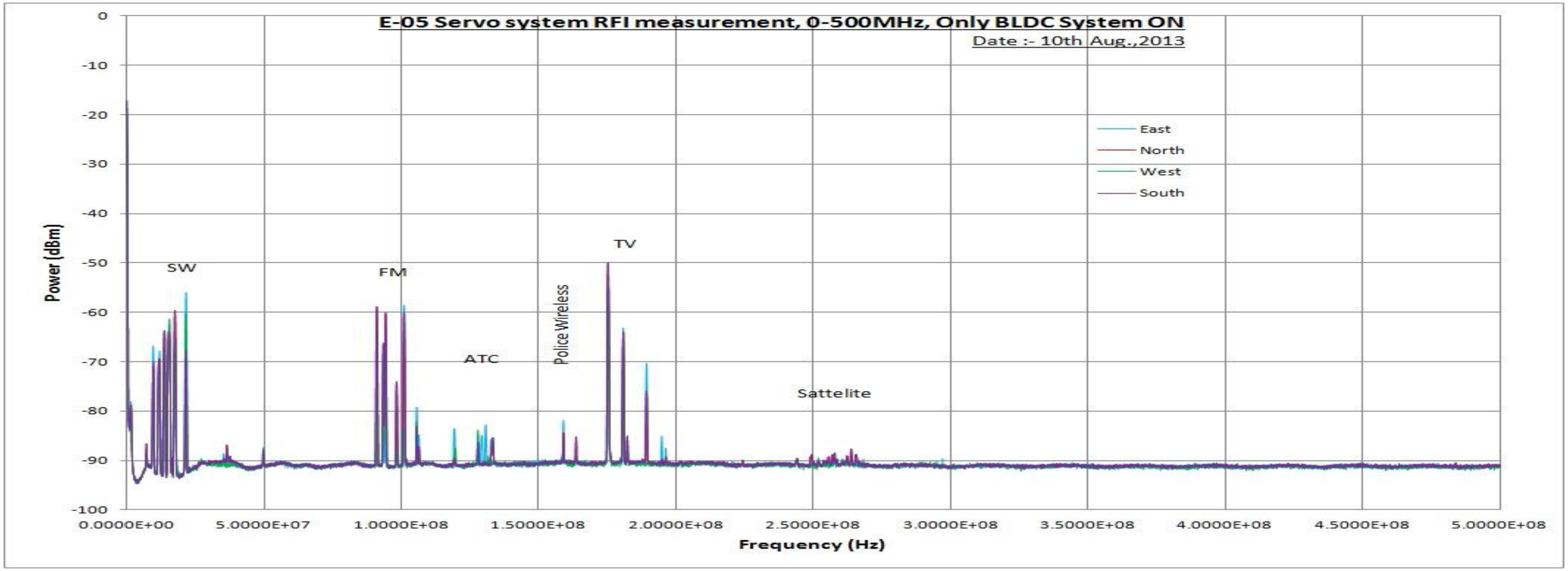
Measurement curve, black: Screening attenuation



Result: The DUT fulfills a minimum screening attenuation of more than 20 dB at horizontal antenna polarization, except for a single resonance at 910 MHz.
In the range of 600-800 MHz the DUT reaches an attenuation of 30 dB.

RFI plot with & w/o brush less drive shows no extra lines

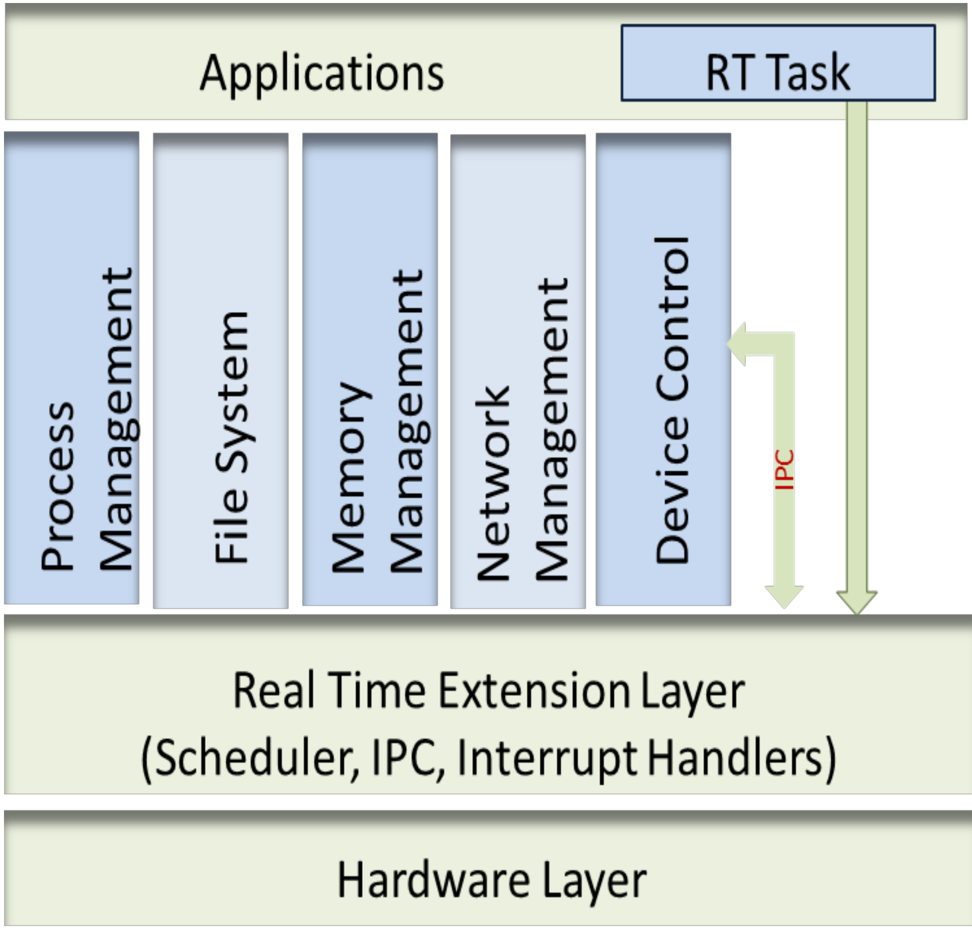




Position controller with Real Time Application Interface

The trajectory and position control is implemented in PC-104 based SBC operating on RTOS with features for modern control algorithms, self diagnostics etc.

- ❑ Hybrid Kernel Approach,
- ❑ Real time applications runs in the real time kernel,
- ❑ Non real time tasks runs in the GPOS kernel,
- ❑ Communication between real time task and GPOS through IPC.
- ❑ API for timers, interrupts, soft irqs, schedulers etc.



software

- The GMRT software is organized as a set of tasks, each task responsible for a particular function. These tasks are executed sequentially in every 100 m-sec.
- The main tasks are

  Data acquisition

  Antenna controller

  Output data

  Host Communication handler
- Another important feature is state machine based design.
- A state machine is a task which may, at any instant of time be in one of
- the several states.
- A state is a condition of a system with regard to the completeness of a function.
- It cannot spend a large block of time in servicing one requirement to the exclusion of all others.

Position Loop Controller (PLC)

PI Compensator with Lead – Lag Filter

$$G(s) = \left[K_p + \frac{K_i}{s}\right] * \left[\frac{1 + sT_{21}}{1 + sT_{22}}\right]$$

Digital Implementation using Tustin Transformation

$$s = \frac{2}{T}\left[\frac{z-1}{z+1}\right]$$

$$Y(k) = a_1 * Y(k-1) + a_{12} * Y(k-2) + b_0 * X(k) + b_1 * X(k-1) + b_2 * Y(k-2)$$

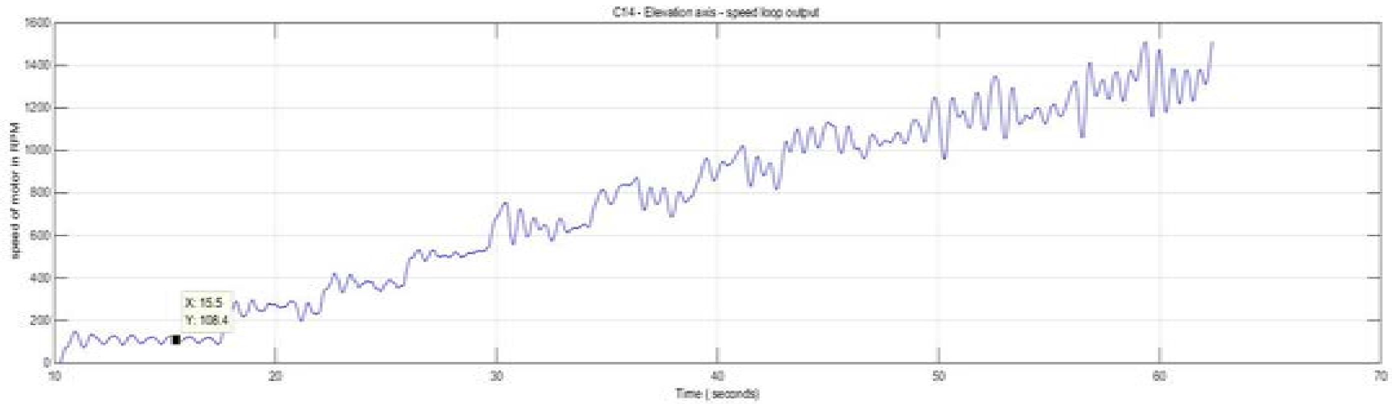
The resulting difference equation above is solved in real-time every 100milli seconds to generate the speed demand.

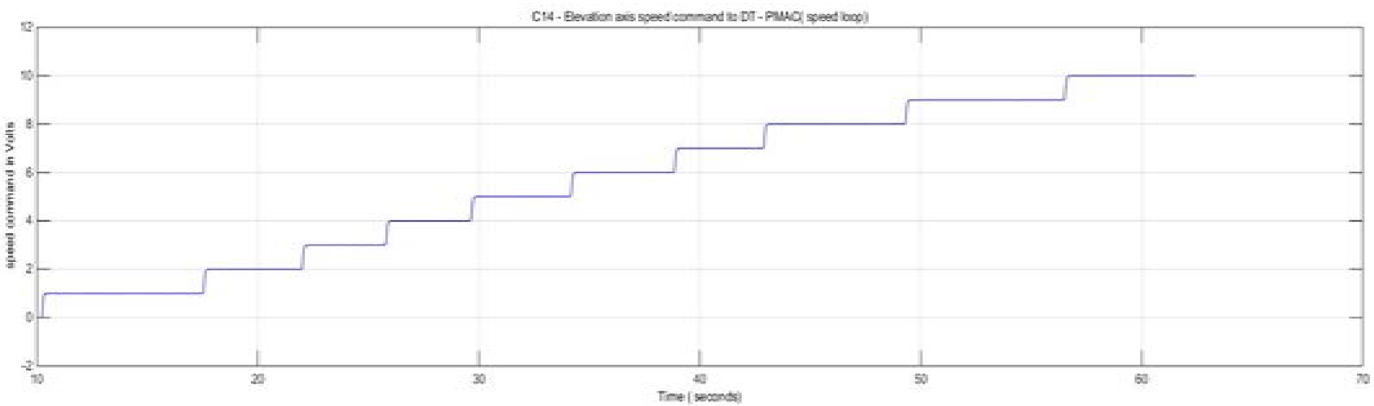
Measurements – speed characterization

- Speed command — output speed

  0 -10 volts — 1200 rpm - elevation axis

  1500 rpm – azimuth axis





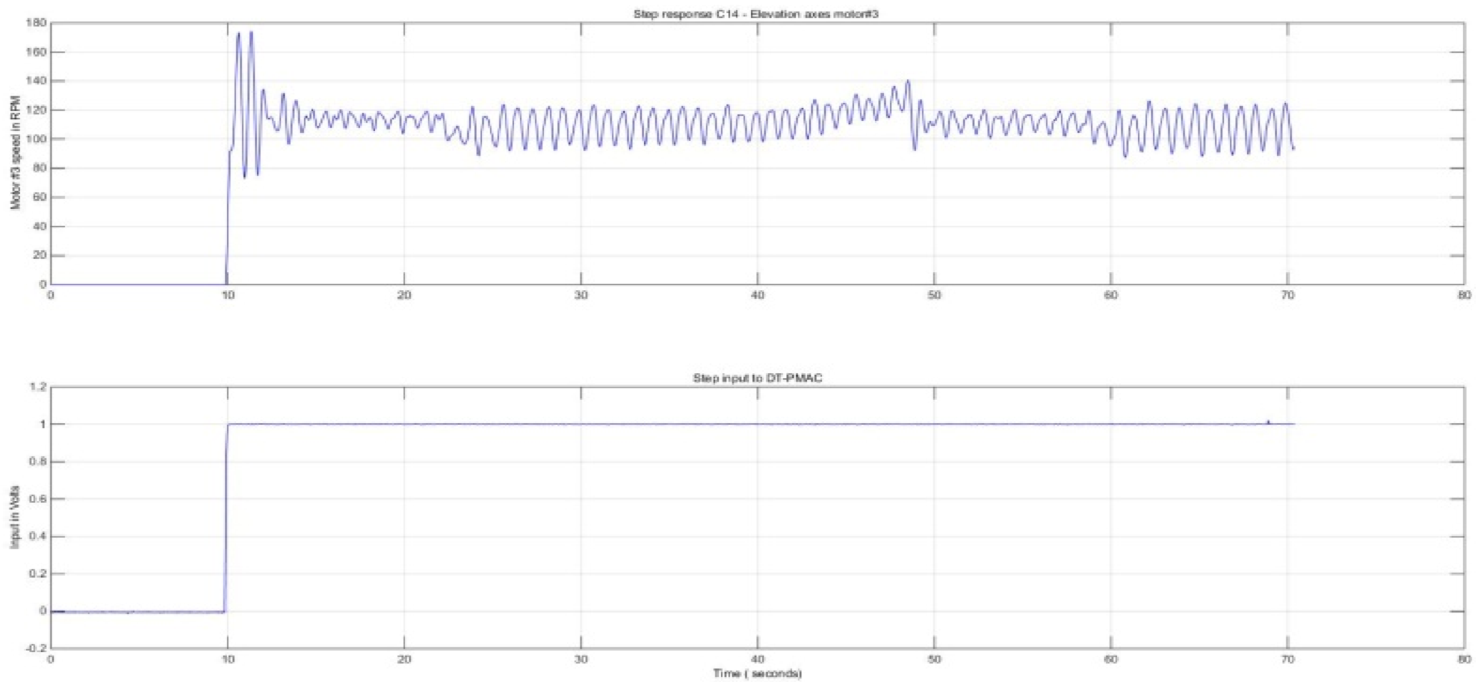
Measurement - speed loop step response

Step response

Rise time - 0.42 secs.

Peak time - 1.50 secs.

Over shoot % - 45.4

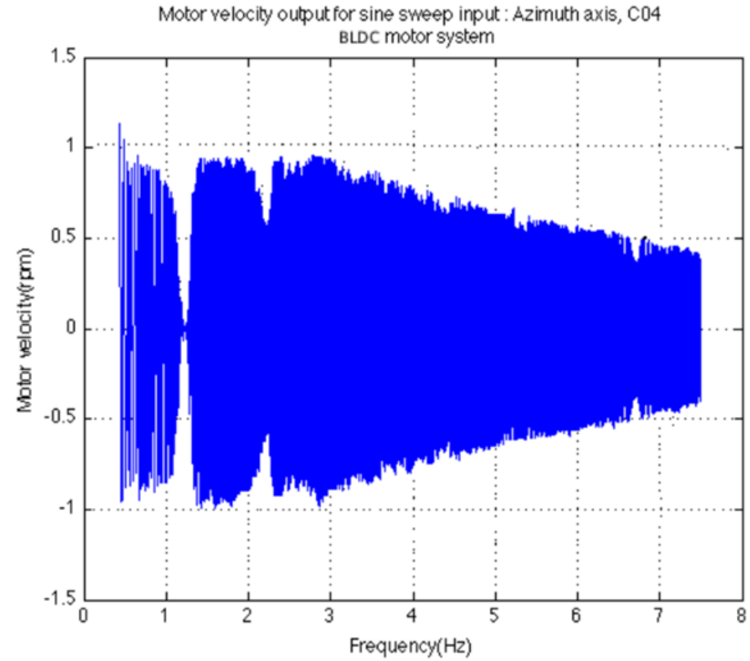


Measurements – Position control

Bandwidth

- The closed loop position bandwidth is tuned to around 0.1 Hz in order to be below the locked rotor frequency around 1.4 Hz,of the mechanical system.

- This provides best tracking and damping characteristics without un neccessarily exciting the natural mechanical resonances.

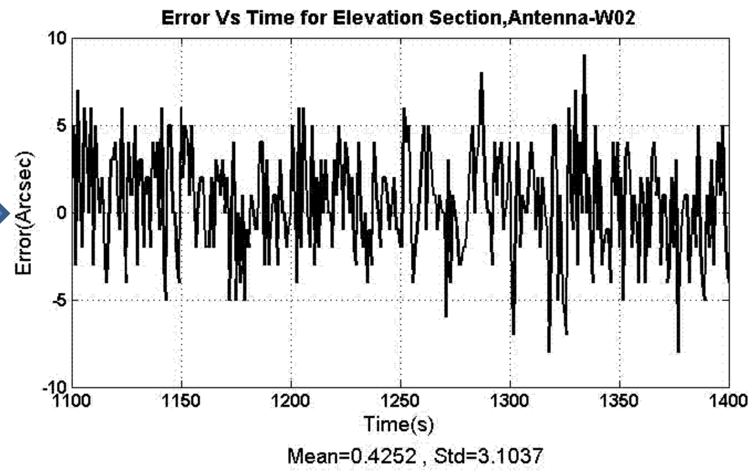


Measurements – Position control & Track

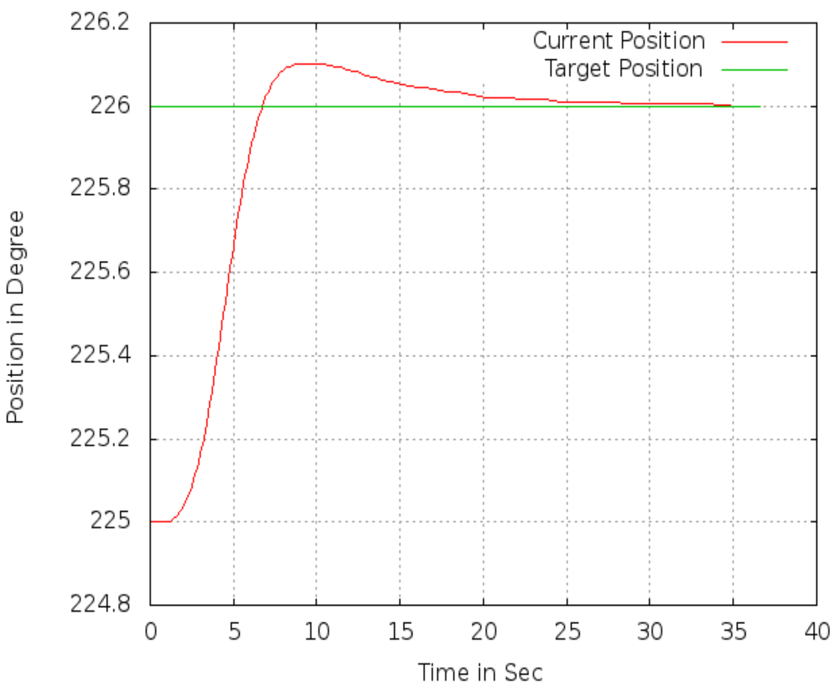
Tracking & Pointing performance

An excellent tracking performance and low speeds pointing is achieved

RMS Error = 4 arc sec



Position loop control step response



Parameters measured

Rise time	-	*3.4 secs*
Peak time	-	*8.8 secs*
Overshoot	-	*10.13 %*
Settling time	-	*21.5 sec*
Steadt state error	-	*78.2 arc sec*
Damping factor	-	*0.72*

Future plans : System Identification - SI

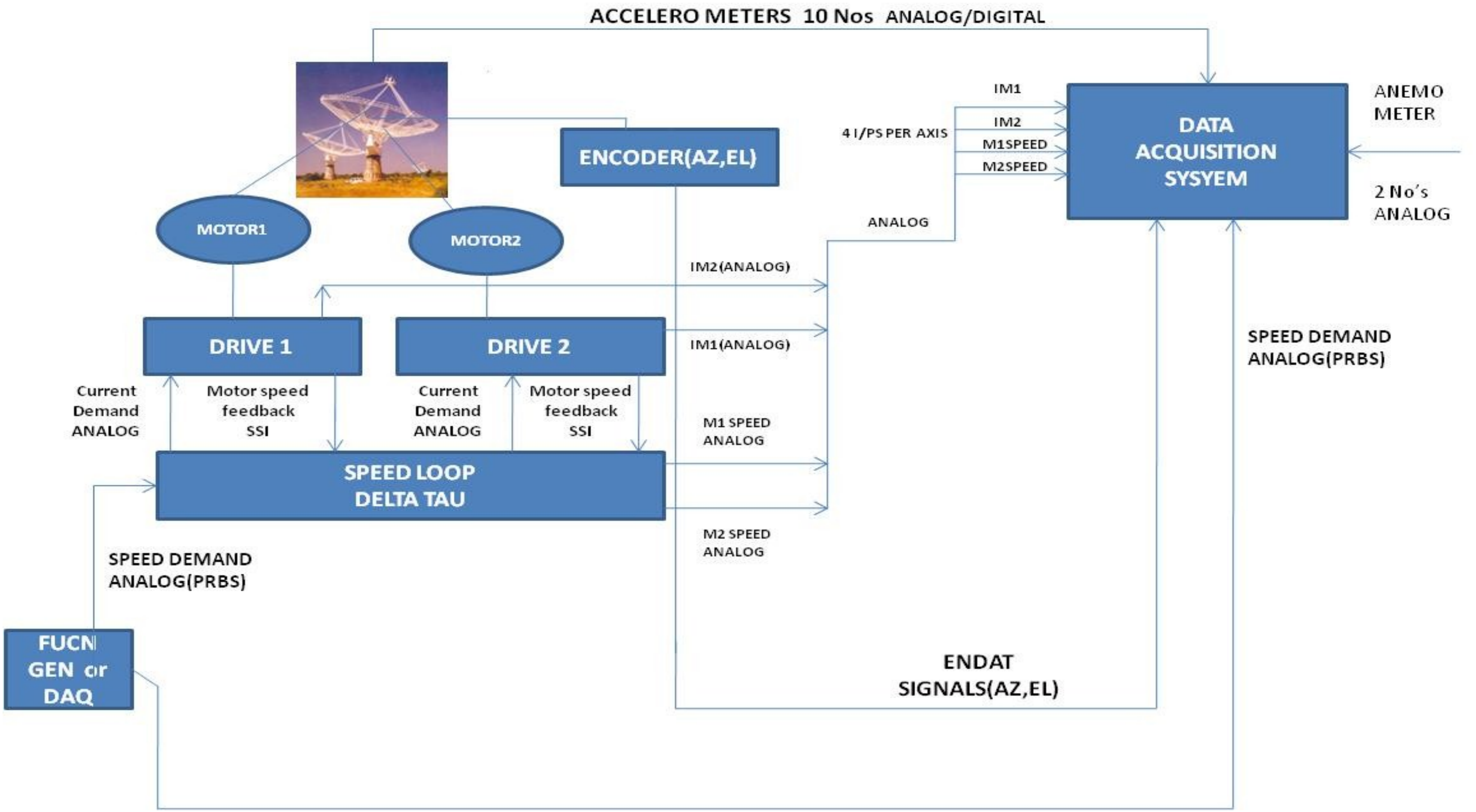
Upgrade GMRT servo system (control laws) for improving tracking accuracy

- Carry out SI to design modern high performance controllers like Linear Quadratic Gaussian (LQG) controller.
- SI is to obtain an analytical model from experimental data.

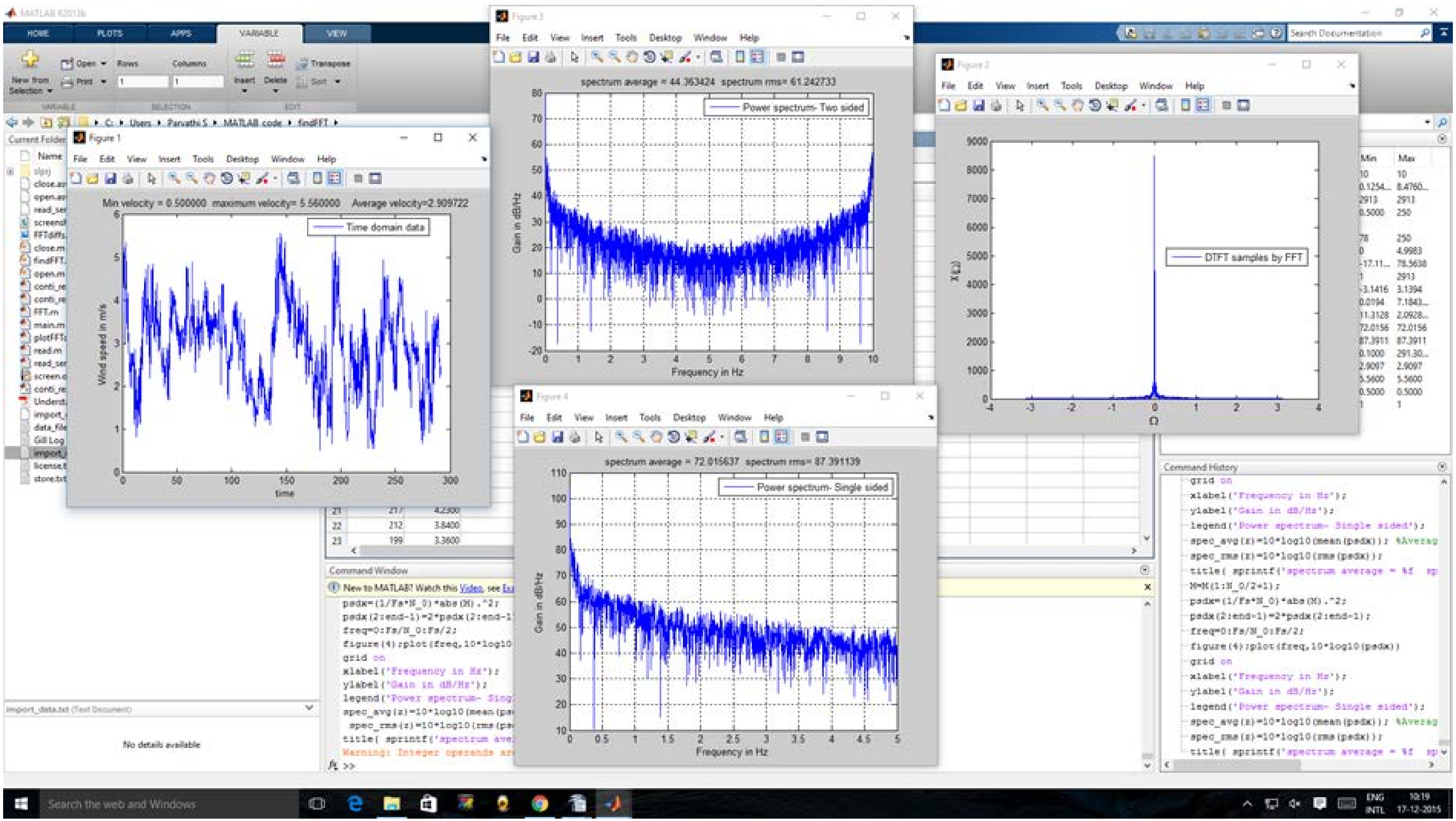
The figure shows the experimental setup

- This experiment is to gather time series data to determine the telescope open loop model in state space form.
- Offline processing of data will give the SI
- Telescope open loop system consists of telescope structure, drive chain and speed feedback.
- SI is performed with closed speed loop and Telescope speed (voltage) is the input.
- The position (encoder) and accelerometer data will be the output of the open loop system open position loop.

A DAQ is used for generating persistent excitation signals like pseudo random binary signal – prbs as well as record typically 5minutes data at a sampling rate of 100Hz.



Wind spectrum at GMRT



THANK YOU

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